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Dear Bob,

We have gone over the literature regarding the Land two-color effect. The general consensus of the responsible scientific community is that Land has created a very clever demonstration of the fact that the subjective sensation of color can be introduced by variables other than the wave length of light. In particular, his demonstrations make excellent use of induction, memory color, and other variables well established in the color literature.

For your background information I am enclosing the following:

1. A compilation of all the articles which have appeared, to date, in Psychological Abstracts.

2. A summary of the state of the art written by an undergraduate student with no previous background in perception. This might be useful to you in communicating the essence of the Land effect to nonpsychologists.

3. Copies of Land's original article in Scientific American (note the obvious editorializing by the Scientific American staff) and what is considered to be the most important article in this field, the Psychological Bulletin paper by the late Gordon Walls. If one could read only two papers, these would be recommended.

In looking over this literature, one is impressed anew with Land's creative genius. There is no question that this is one of the finest minds in the contemporary scientific community. However, like so many other gifted individuals in our technology, his training in psychology was not as complete as one would have hoped. He has undoubtedly created a spectacular demonstration and deserves much credit for it. However, the theoretical basis of the demonstration represents nothing new and can, in fact, be misleading to the layman.

With respect to the problem you are working on at the moment, the entire Land phenomenon seems to me to be interesting but not particularly

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relevant. At least this is the impression that I obtained after talking to you during my last visit to Washington.

If you would like any clarification and/or expansion of these materials, please do not hesitate to let me know.

With best regards,

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HWL:ci

Enclosure

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From Psychological Abstracts

1959 through March, 1968

(Chronological Order)

Land, E. H. Experiments in color vision. Scientific American, 1959, 200, (5), 84-99.
A comprehensive explanation with a dozen illustrations of Land's hypothesis that "color in natural images depends on a varying balance between longer and shorter wavelengths over the visual field." (Copy enclosed)

Land, E. H. Color vision and the natural image. Part II. Proc. Nat. Acad. Sci., Washington, 1959, 54, 636-644.
Experiments are described which develop and confirm the hypothesis that "color, at least in images derived from two primaries, depends neither on the wave lengths of these primaries nor on the relative energy of these primaries at a given point in the image." Colors are predicted from a "ratio of ratios; namely, as numerator, the amount of a long-wave stimulus at a point as compared with the amount that might be there; and, as denominator, the amount of a shorter wave stimulus at that point as compared with the amount that might be there." (Part I was not abstracted. It appeared in Volume 45, #1, Jan.,1959, pps. 115-129.)

Hartline, H. K. (chairman) Symposium on new developments on the study of color vision. Proc. Nat. Acad. of Sci., Washington, 1959, 45, 89-129.
E. H. Land reports experiments on creating a fully chromatic image from simultaneous projection of two appropriately filtered monochromatic images.

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Woolfson, M. M. Some new aspects of color perception. I.B.M. J. Res. Develpm., 1959 (Oct.), 3, 313-325.
A mathematical analysis is made of Land's recent experiments which showed that fully colored pictures can be produced by a 2-color projection system. Although Land's results had apparently been at variance with the classical theories of color perception, it has now been found possible to explain the experiments within the framework of those theories and in conjunction with well-known phenomena in the field of experimental psychology. The results are interpreted in terms of a mechanism of color transformation.

Walls, Gordon L. "Land! Land!" Psychol. Bull., 1960 (Jan.) 57, 29-48.
The recent theoretical analysis of Land has been received by some as the ultimate in understanding color vision. When the features of the theory are contrasted with prior formulations and the data, assertion is made that "I am quite content with being able to explain why Land gets what he does get, using only old knowledge and old language and making no use whatsoever of Land's fantastic new hypotheses and new concepts." (Copy enclosed)

Land, E. H. Some comments on Dr. Judd's paper. J. Opt. Soc. Amer., 1960, 50, 268.
The writer refers to Judd's appraisal of his work with two-primary color projections. Judd's formulas are "wave-length rich and time dependent; our experiments demand formulas which are nearly independent of wave-length and fully independent of time."

Judd, Deane B. Appraisal of Land's work on two-primary color projections. J. Opt. Soc. Amer., 1960, 50, 254-268.
It is shown that no new theory is required for the prediction of Land's

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result that two-primary color projecti can produce object-color perceptions of all hues; nor for his result that many choices of pairs of primaries yield substantially the same object-color perceptions. Land's hypothesis that when the colors of the patches of light making up a scene are restricted to a one-dimensional variation of any part, the observer usually perceives the objects in that scene as essentially without hue, is new; several special cases of it are supported by previous work as well as Land's. (Copy enclosed)

Yilmaz, Huseyin. On color perception. J. Opt. Soc. Amer., 1960, Program Suppl., 20-Abstract.
Note: Yilmax is not to be taken seriously, H.W.L.

Teevan, R. C. and Birney, R. C. (Eds.) Color Vision: An Enduring Problem in Psychology. Selected Readings. Princeton, New Jersey: Van Nostrand, 1961, ix, 214 p. $1.45.
Part II reprints modern experimental and theoretical papers by investigators including E. H. Land.

Land, E. H. and Daw, N. W. Binocular combination of projected images. Science, 1962, 138, 589-590.
Two color-seperation positive transparencies of a scene, one projected with "red" light and the other with tungsten lamp light, were superimposed on a screen. The light was polarized so that an O wearing an appropriate viewer could see both images in each eye or the "red" image in one eye and the "white" image in the other. These two situations gave different results, not the same results, as some previous investigators have claimed. Land's major results cannot be obtained "stereoscopically."

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We conclude that the process by which color is formed could possibly be a process of the retina or the lateral geniculate body, and does not necessarily have to be a process of the cerebral cortex as implied by the binocular experiments which purported to give the fuller gamut of color.

Belsey, Richard. Color perception and the two-color projection. Journal of the Optical Society of America, 1964, 54 (4), 529-531.
Land, using only two projecting primaries, demonstrated a wide range of hues in "natural image" projections. Nineteen Os with normal color vision viewed Land-type projections and identified the hues perceived with a colormeter. Results indicate that the wide range of hues perceived was the result of a primary induction due to contrast phenomena ("colored shadow" effect) and a secondary distortion toward the memory color of familiar objects.

Mattheeuws-Hambrouck, M. Les phenomenes de Land et la psychophysique des couleurs de contraste. (The Land phenomena and the psychophysics of contrasting colors.) Psychologica Belgica, 1965, 5, 27-39.
Two figures presenting colors and stimuli demonstrate Land's coordination system and the results he achieves. New experiments are also reported.

Miscellaneous

Land, Edwin H. The Retinex, American Scientist, Vol. 52, #2, June, 1964, 247-264.
This is a semi-popular address given on the occasion of the award of a prize to Dr. Land, in which he describes his color theories. The reference section contains a good list of articles.

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Some interesting comments appear in "Color Vision," Annual Review of Psychology, 11, 1960, by Hurvich, Leo, M.and Jameson, Dorthea.

Land distributes privately a two page phamplet "Photographing for Two Colour Projection." This may be obtained by writing to Dr. Land, Polaroid Corporation, Cambridge, Massachusetts, 02139.

Bello, Francis. An astonishing new theory of color, Fortune Magazine, May, 1959. A popular article, poorly written scientifically by a journalist.

An excellent summary may be found in "Vision and Visual Perception," C. H. Graham, Ed., Wiley, 1965, p. 469-472.

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The Land Effect: A Brief Summary

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E. H. Land, using only a two-primary color projection, found it possible to reproduce a wide range of hues; what he termed full-color natural images. To obtain these images, Land used two different photographs of the same scene and two different wavelengths for illuminating them. The longer wavelength is passed through the long-wave photograph (long record), and the shorter wavelength is passed through the short-wave photograph (short record). Land attributes the resulting "full color" to the interplay of longer and shorter wavelengths. He posits a "ratio of ratios" able to predict colors; "namely, as numerator, the amount of a long-wave stimulus at a point as compared with the amount that might be there; and, as denomenator, the amount of a shorter wave stimulus at that point as compared with the amount that might be there."

Using filters to produce the necessary pair of photographs, Land comments that filters produce bands of wavelengths, not single wavelengths. The width of the bands apparently makes little difference as long as the long record is paired with the longer band, and the short record is paired with the shorter band. Land has, in fact, used a red filter for the long record and no filter at all (white light) for the short record. As wave-lengths may vary, so may the relative intensity of beams over the whole field.

To account for his results, Land found it necessary to discard classical color theory as being too simplistic. The work of Newton and his followers "had very little to do with color as we normally see it.

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They dealt with spots of light, and particularly with pairs of spots, trying to match one to another. The conclusions they reached were then tacitly assumed to apply to all of color sensation." Land contends that the study of color vision under natural conditions in complete images is a situation incomparable to the study of spots in their surrounds. Land comments that "for all its beauty the (Newtonian) spectrum is simply accidental consequence of arranging stimuli in order of wavelength. The significant scale for images runs from warm colors through neutral colors to cool colors." A new color theory and a new visual scale are considered necessary. Land has said that "the eye can build colored worlds of its own," attributing the full color sensation to a yet undiscovered property of the retina. He awaits verification from more physiologically inclined sources.

Objection may be made to Land's findings on both practical and theoretical grounds. Practically, it is necessary to determine that Land's images are, in fact, full color. Theoretically, one must look for an explanation of the Land phenomenon in classical color theory before abandoning it in favor of Land's own theoretical framework.

Practically, there is no doubt that two color-separation transparencies are much more that two-thirds as good as three transparencies. This is not a new discovery, having been graphically demonstrated by

STAT [redacted] in 1943. According to Walls, Land's claim to full color is not entirely accurate: reproduction of the copy colors is not completely faithful, and, although many colors are produced by Land's technique, there are important hues missing and unobtainable. For instance, there are no pure blues or pure greens--

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only varying degree of a blue-green mixture. The fact that the mixture can be more blue than green, and the fact that some objects are commonly blue, may account for a projected color (of the sky, for example) appearing blue. Land's images, thus, might only be termed full color verisimilitude.

Regarding Land's theory, Walls concludes that he is "quite content with being able to explain why Land gets what he does get, using only old knowledge and old language and making no use whatever of Land's fantastic new hypotheses and new concepts." Walls sees Land's images as being so many spot-and-surround situations and "the color of any spot is at the mercy of a different spectral composition in its surround unless the luminance of the spot is much higher than that of the surround." Walls sees Land's extra colors resulting from simultaneous color contrast or "spatial induction of complementary hue."

The same phenomenon is explicable through lateral, general, and local adaptation STAT color conversion may account for the case when spot and surround have the same chromaticity but different intensities. Regarding induction, Walls mentions that "whatever hue is induced into a spot is inevitably complementary to whatever light, in the surround, is doing the inducing. This is not to say, however, that the surround and spot will necessarily be seen in complementary colors. In Land's pictures this is rarely the case--which unquestionably influenced him to reject a 'contrast explanation.'" A light's mixture complement and induction complement are not the same in hue. Further, a physically chromatic surround may not appear colored. An apparent color, too, may be a mixture of an actual and an induced color. There is also

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the colored shadow effect which may account for a great portion of Land's obtained hues.

In brief, then, we see that Land's effect is, in practice, somewhat less that full color. We note, also, that there are classical explanations which need not be altogether discarded in accounting for the Land effect.

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MEMORANDUM FOR: [redacted] STAT

FYI

I have copies of the flagged [redacted] STAT
a title - Bla. Also I advertise affiliation with us. [redacted] STAT

1 Oct.
(DATE)

FORM NO. 101 REPLACES FORM 10-101
1 AUG 54 WHICH MAY BE USED. (47)

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